

Neutrino Astronomy at the South Pole

AMANDA and IceCube



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Outline

The Neutrino

Detecting Neutrinos

Neutrino Astronomy

Working at the South Pole

AMANDA and IceCube

Prediction of the Neutrino

"I have done a terrible thing -
I have invented a particle that
cannot be detected"

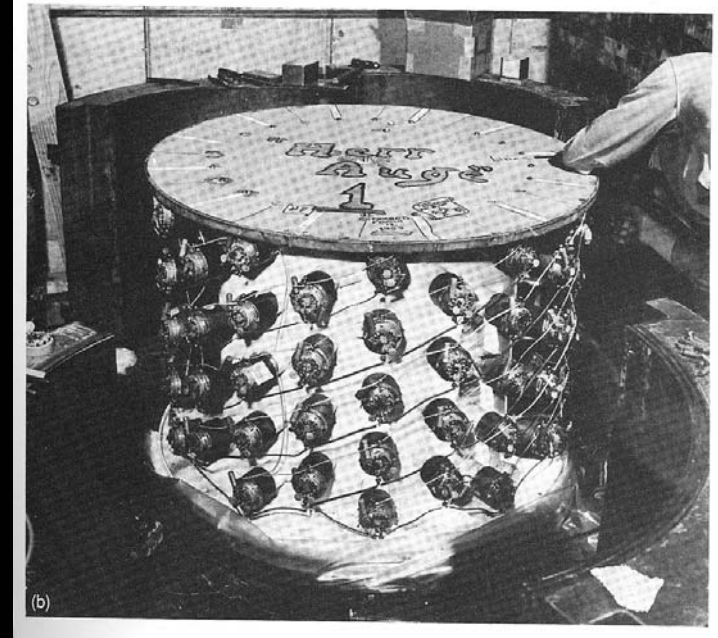
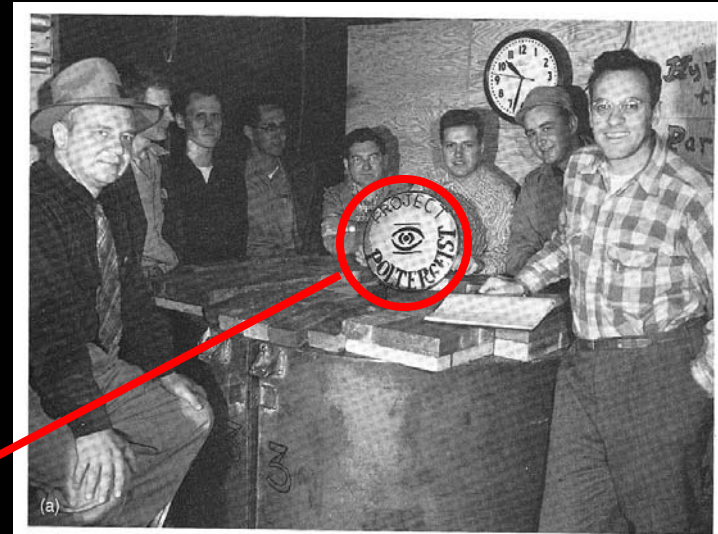
-- Wolfgang Pauli, 1930



Experimental results for nuclear
beta decay required either an
"invisible" particle or violation of
the laws of conservation of
momentum and energy.

Discovery of the ν

- 1956 - Fred Reines and Clyde Cowan detect neutrinos from the sun



ν properties (~50 years later)

FERMIONS

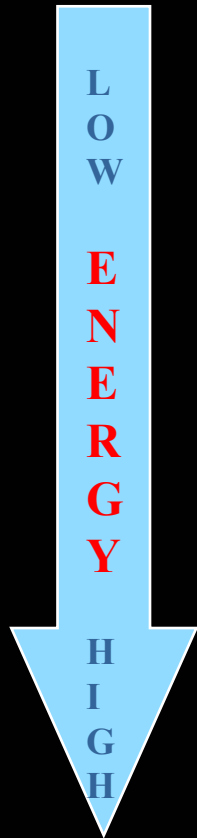
matter const
spin = 1/2, 3/2

Leptons spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge
ν_e electron neutrino	$< 1 \times 10^{-8}$	0
e electron	0.000511	-1
ν_μ muon neutrino	< 0.0002	0
μ muon	0.106	-1
ν_τ tau neutrino	< 0.02	0
τ tau	1.7771	-1

Quarks	
Flavor	Mass GeV/c ²
U up	0.002 - 0.005
C charm	1.3 - 1.5
S strange	0.005 - 0.01
t top	173.1
b bottom	4.18

ν oscillations imply ν mass

Neutrino sources



The Big Bang		10^{-3} eV
Radioactive decay		10^3 eV (KeV)
Nuclear fission reactors		
Nuclear fusion reactor (the Sun)		10^6 eV (MeV)
Supernovae		
Particle collisions		
Accelerators		
Cosmic rays in the atmosphere		10^9 eV (GeV)
WIMP annihilation	??	
Active Galactic Nuclei	??	10^{12} eV (TeV)
Gamma Ray Bursts	??	10^{15} eV (PeV)

AMANDA/IceCube

Neutrino Fluxes

Sources of ν 's

(1 MeV = 1.6×10^{-13} Joules)



The Big Bang

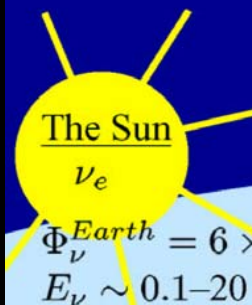
$$\rho_\nu = 330/\text{cm}^3$$

$$E_\nu = 0.0004 \text{ eV}$$



SN1987

$$E_\nu \sim \text{MeV}$$



The Sun

$$\nu_e$$

$$\Phi_\nu^{\text{Earth}} = 6 \times 10^{10} \nu/\text{cm}^2\text{s}$$

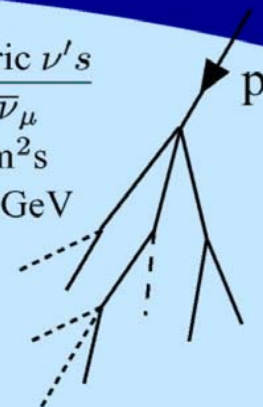
$$E_\nu \sim 0.1\text{--}20 \text{ MeV}$$

Atmospheric ν 's

$$\nu_e, \nu_\mu, \bar{\nu}_e, \bar{\nu}_\mu$$

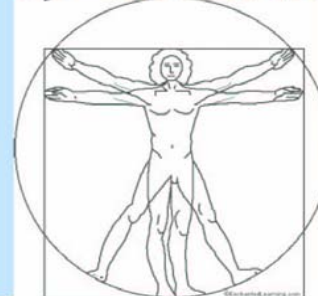
$$\Phi_\nu \sim 1 \nu/\text{cm}^2\text{s}$$

$$E_\nu \sim 0.1\text{--}100 \text{ GeV}$$



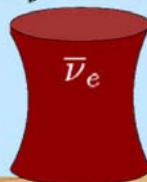
Human Body

$$\Phi_\nu = 340 \times 10^6 \nu/\text{day}$$



Nuclear Reactors

$$E_\nu \sim \text{few MeV}$$



Accelerators

$$E_\nu \simeq 0.3\text{--}30 \text{ GeV}$$



Earth's radioactivity

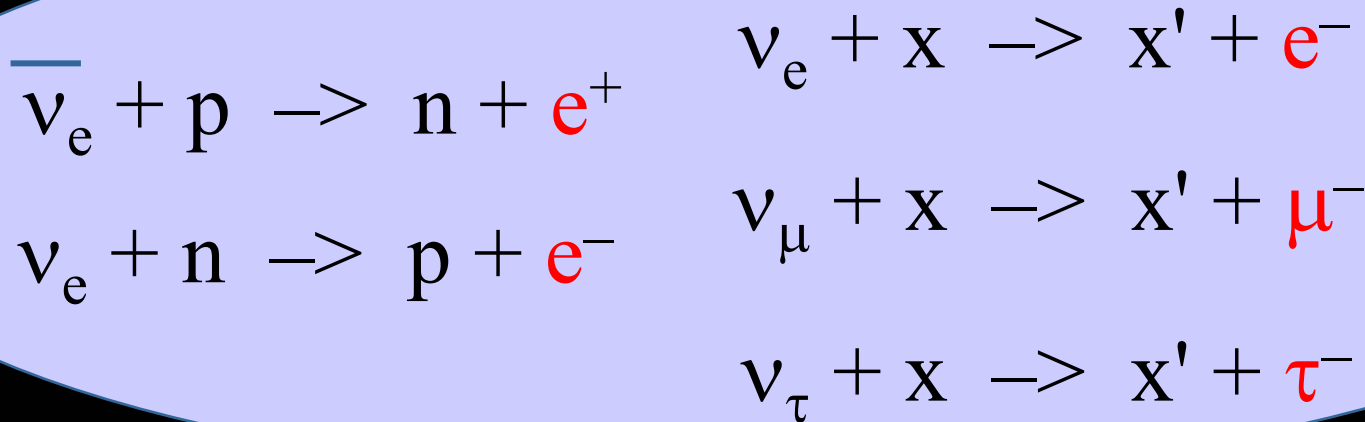
$$\Phi_\nu \sim 6 \times 10^6 \nu/\text{cm}^2\text{s}$$



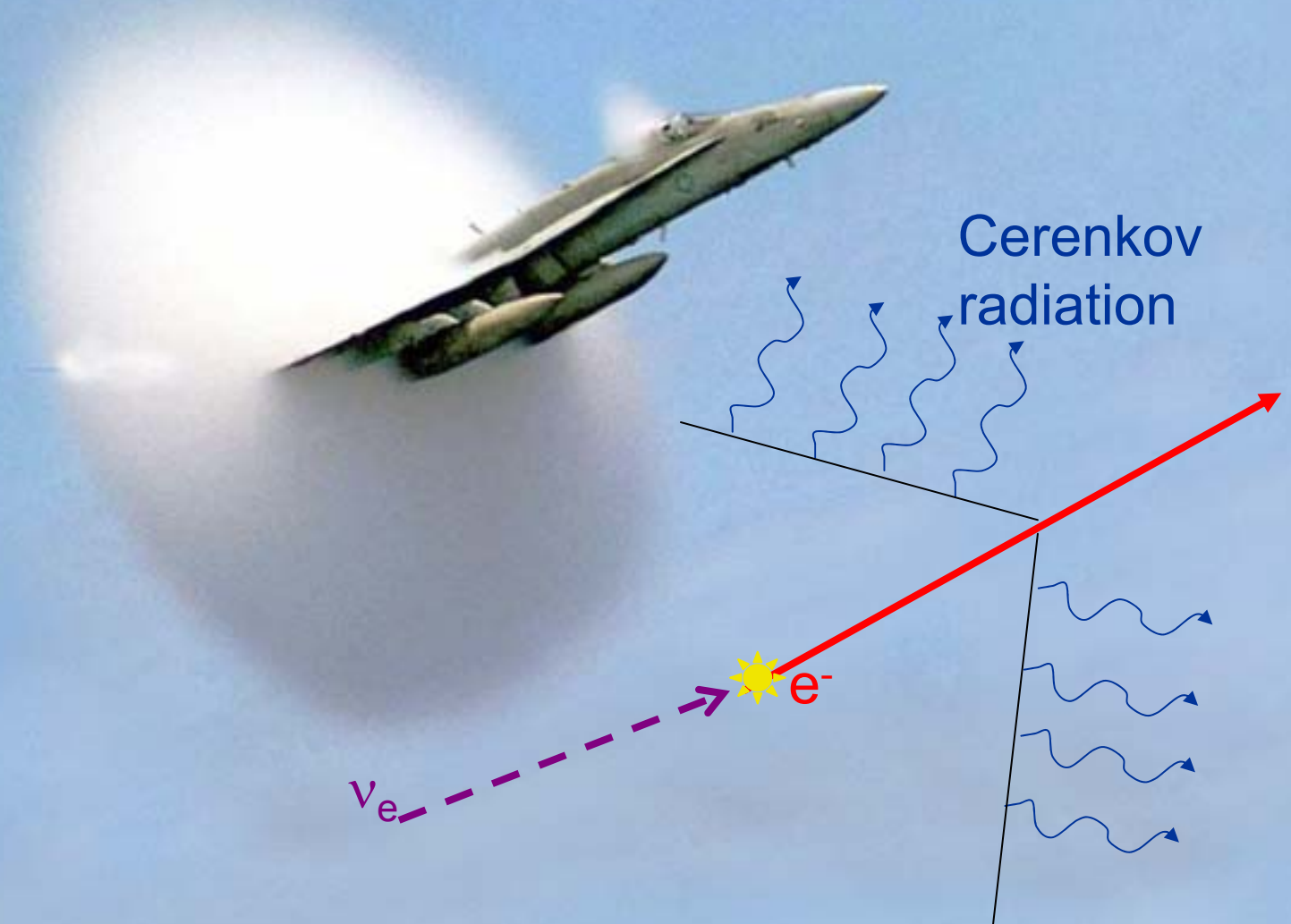
II. Neutrino Detection

Since neutrinos interact only through the weak force, they have enormous range. (Solar neutrinos easily penetrate a light-year of lead.) This also makes them difficult to detect.

A neutrino is not detected "directly" – it leaves no visible track. Neutrinos are detected when they collide with matter and produce fast-moving charged particles that are detectable.



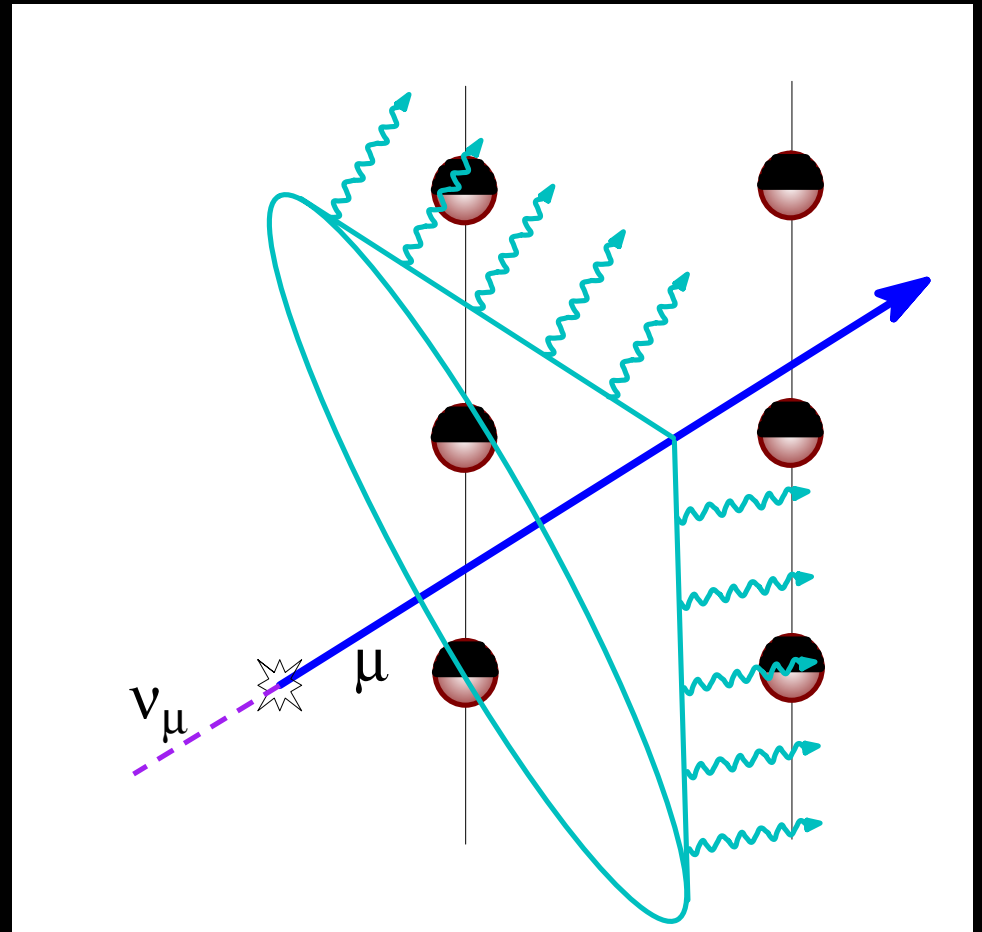
Cerenkov radiation – the electromagnetic “sonic boom”



Cherenkov photons are detected by arrays of photomultiplier tubes

Tracks are reconstructed from the arrival times of the photons.

1 clock tick = 50 nanoseconds



Requirements for a Cherenkov Neutrino Detector

1. Large volume of transparent medium
2. Shielding from Cosmic Rays

1. Water

2. Deep water

Ocean

Lake (e.g., Baikal)

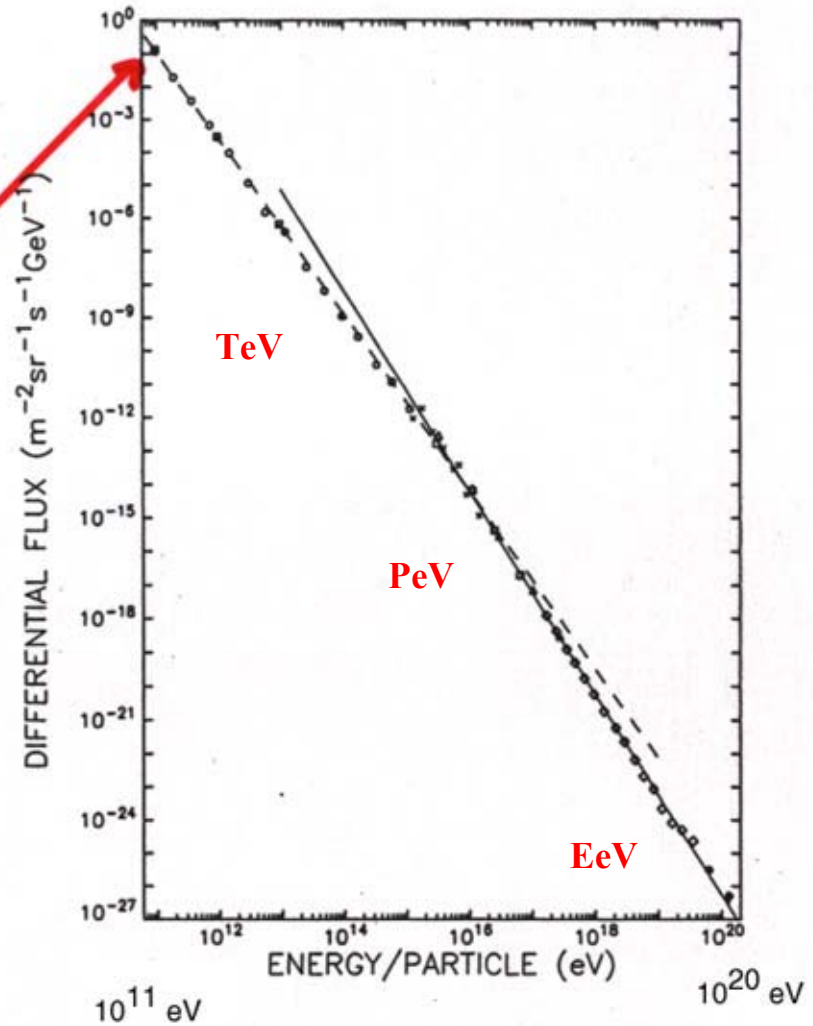
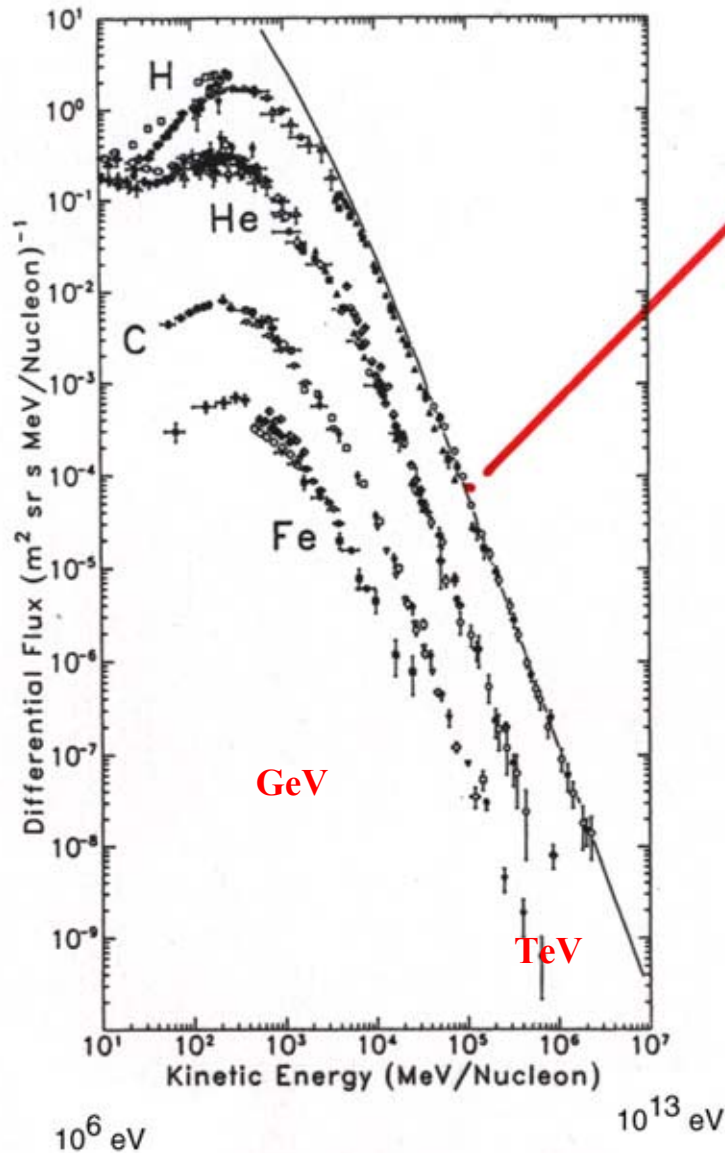
Ice

III. Neutrino Astronomy

Mapping the neutrino sky

- Why high-energy neutrinos can be used for astronomy.
 - Neutrinos point back to their source
 - Neutrinos have no electric charge
 - Not deflected by magnetic fields
 - Neutrinos are "not absorbed" by matter
- Neutrinos will be produced at the same sites where high-energy cosmic rays originate

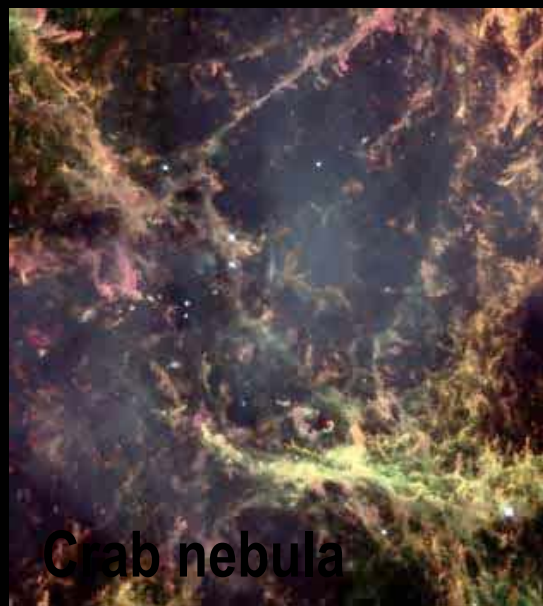
Cosmic Ray Energy Spectrum



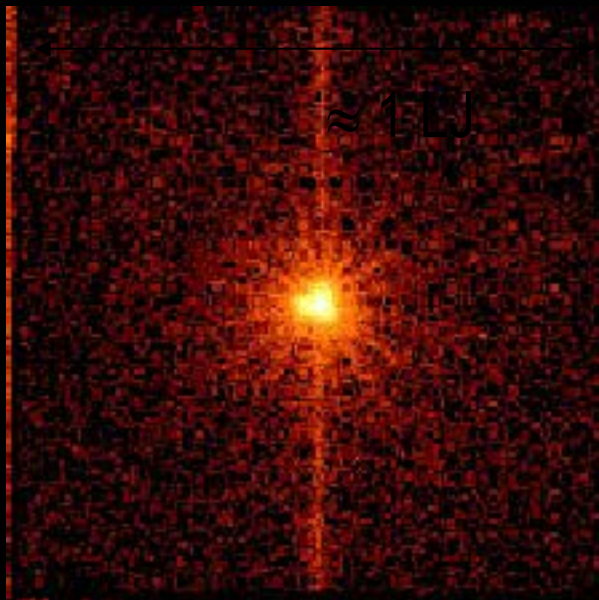
14 orders of magnitude
In the cosmic ray sky

Cosmic Ray and Neutrino source candidates

Supernova remnant



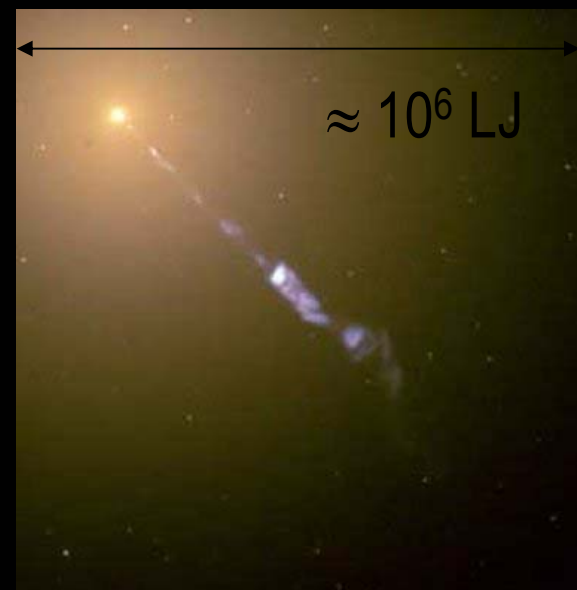
Microquasar



Black hole with
 \approx mass of sun

galactic

Active Galaxy



Black hole with
 $10^8 \times$ mass of sun

extra-galactic

Active Galactic Nuclei

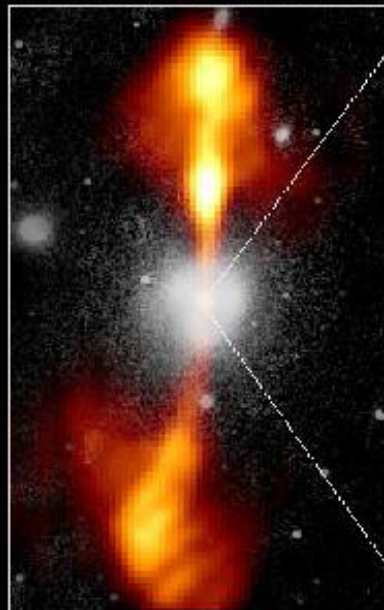
Most models assume a central black-hole and accretion disk.
Particle acceleration occurs either near the black hole or in the jet

Core of Galaxy NGC 4261

Hubble Space Telescope
Wide Field / Planetary Camera

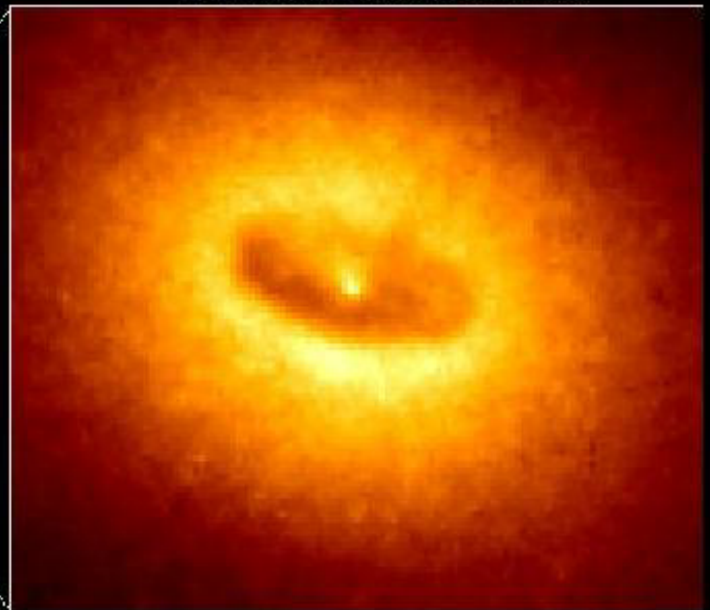


Ground-Based Optical/Radio Image



380 Arc Seconds
88,000 LIGHTYEARS

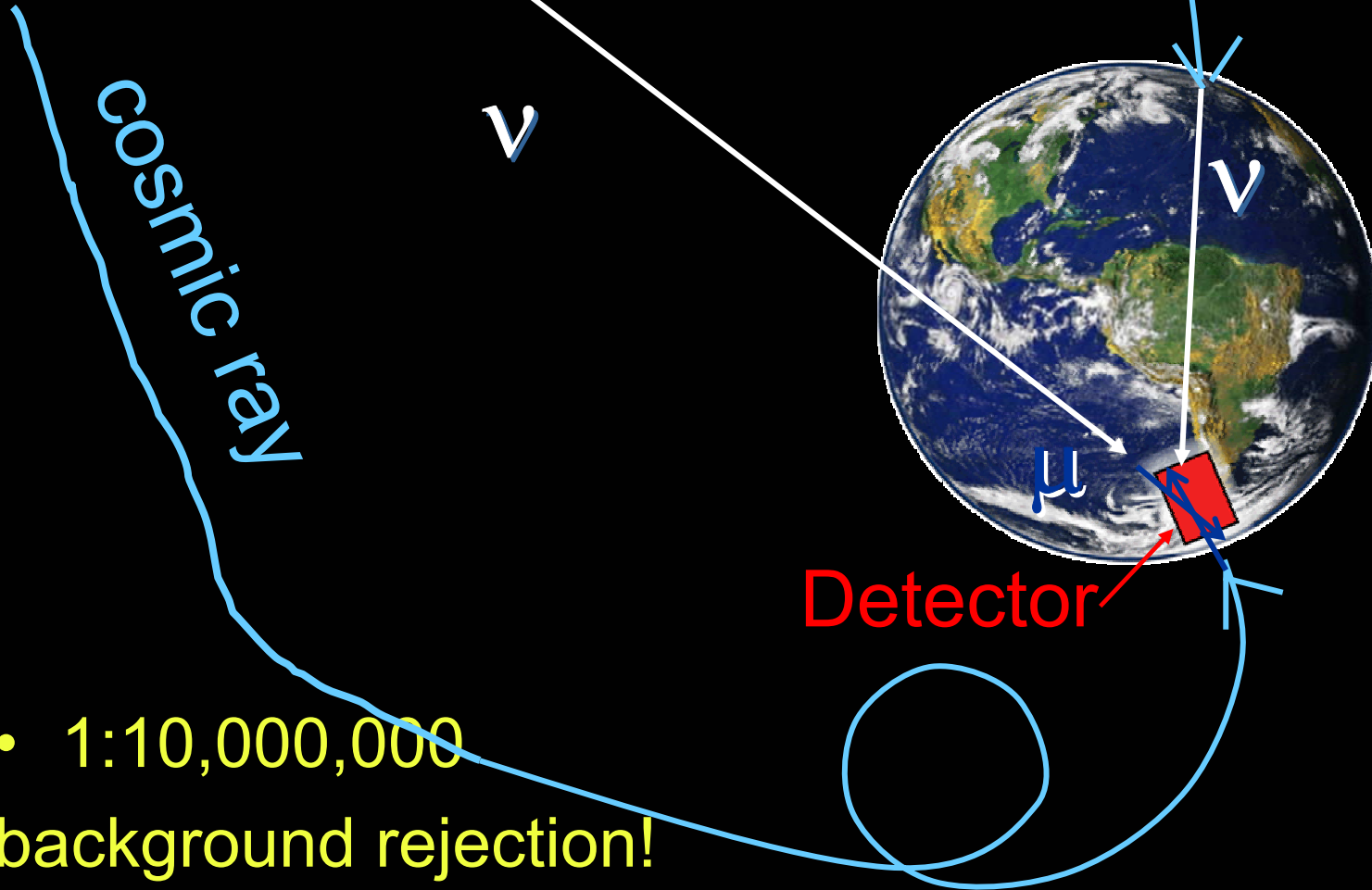
HST Image of a Gas and Dust Disk



17 Arc Seconds
400 LIGHTYEARS

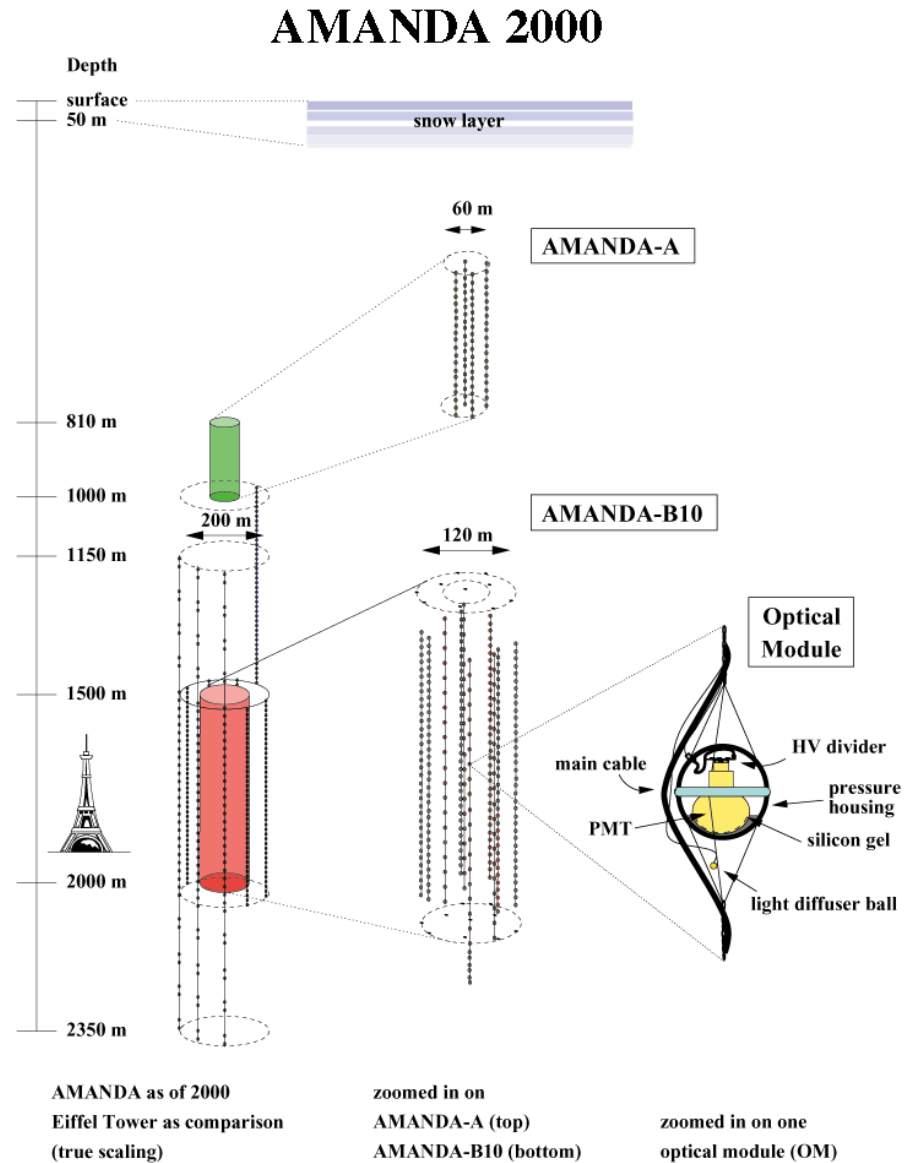
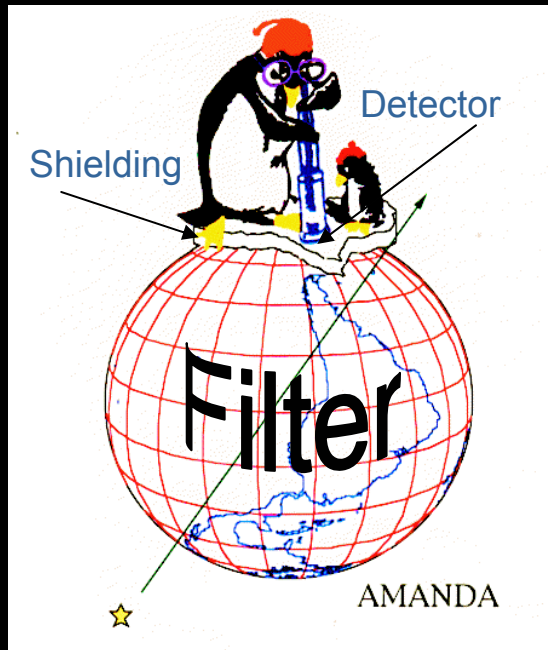
cosmic ray

- Look for the neutrino's interaction product (e, μ, τ)
- Use the earth as a filter

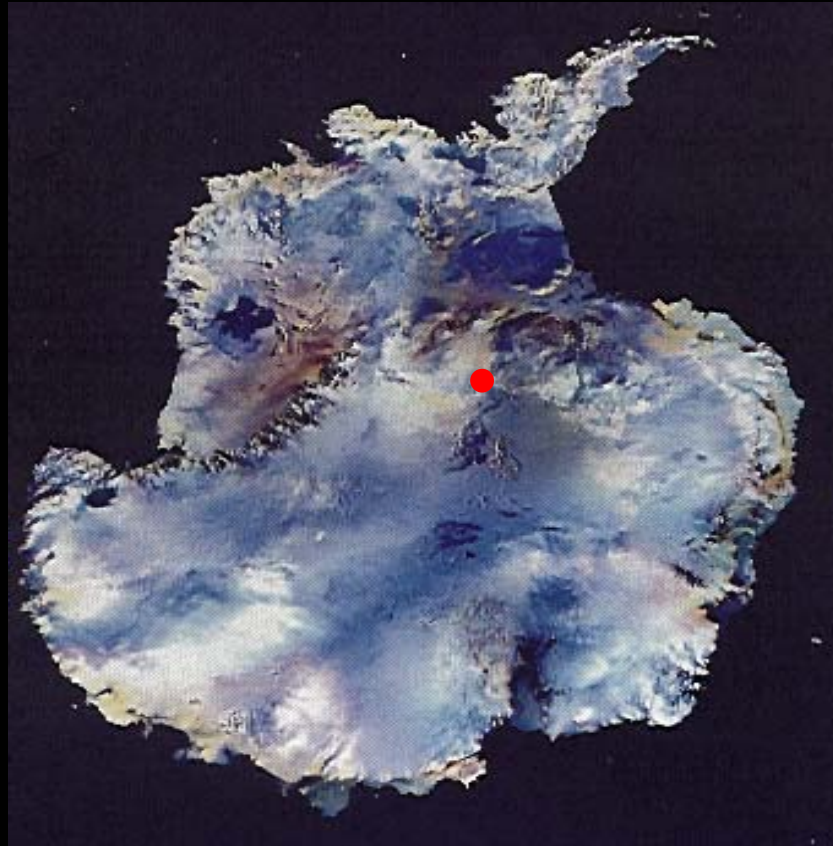


- 1:10,000,000
background rejection!

The Antarctic Muon And Neutrino Detector Array



IV. Working at the South Pole





INTERNATIONAL ANTARCTIC CENTRE

Antarctica New Zealand

ANTARCTIC HERITAGE TRUST

UNITED STATES ANTARCTIC PROGRAM

NATIONAL SCIENCE FOUNDATION

AIR NATIONAL GUARD DETACHMENT 13

ANTARCTIC SUPPORT ASSOCIATES

ICAIR (INTERNATIONAL CENTRE FOR ANTARCTIC INFORMATION AND RESEARCH.)

ITALIAN ANTARCTIC RESEARCH PROGRAMME

UNEP/GRID - Christchurch

(UNITED NATIONS ENVIRONMENT PROGRAMME
GLOBAL RESOURCE INFORMATION DATABASE)



WHEN RAIN
COMES, CLOTHING IS
KING



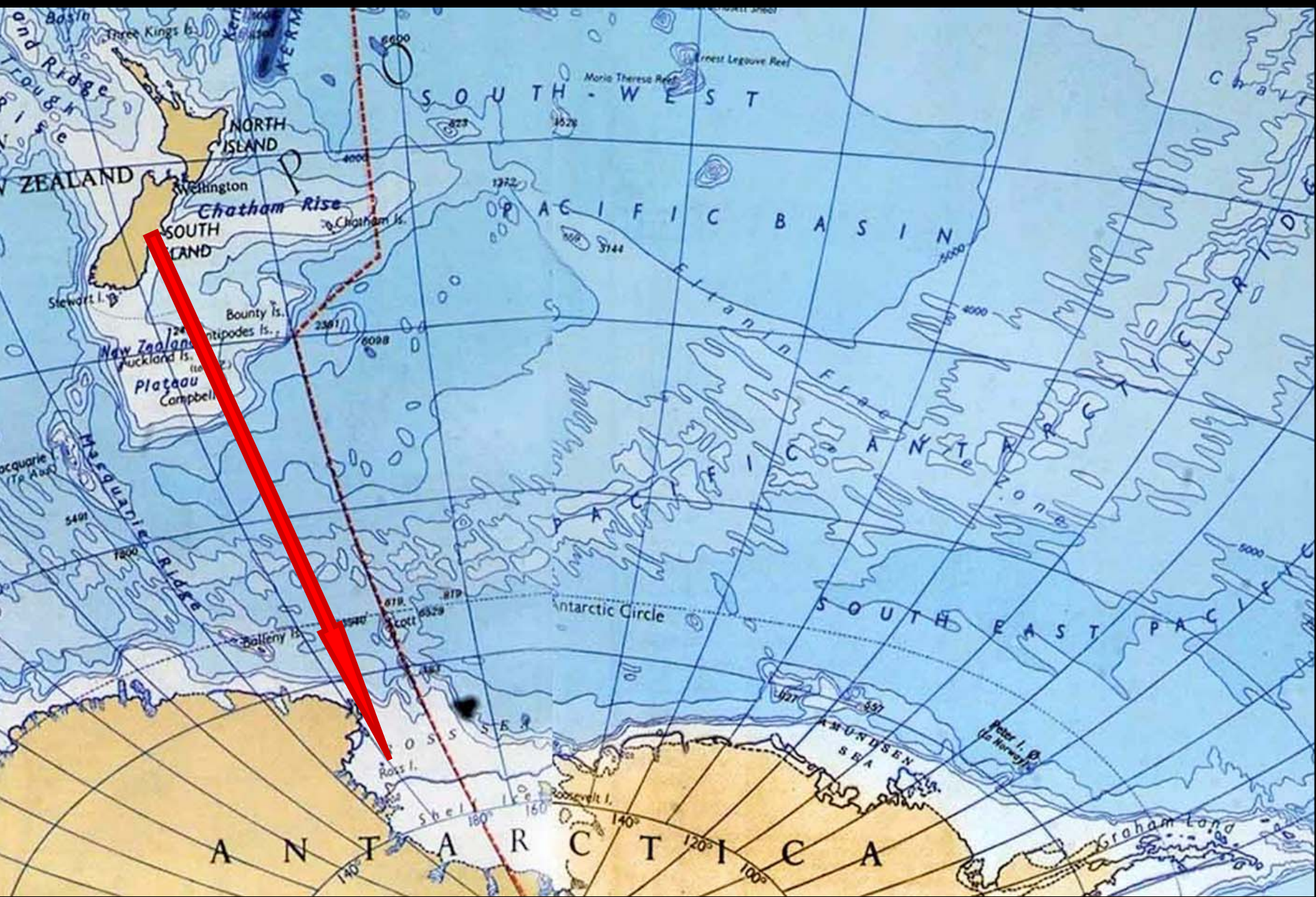


U.S. AIR FORCE

Pride of Glenville

1094

(100)



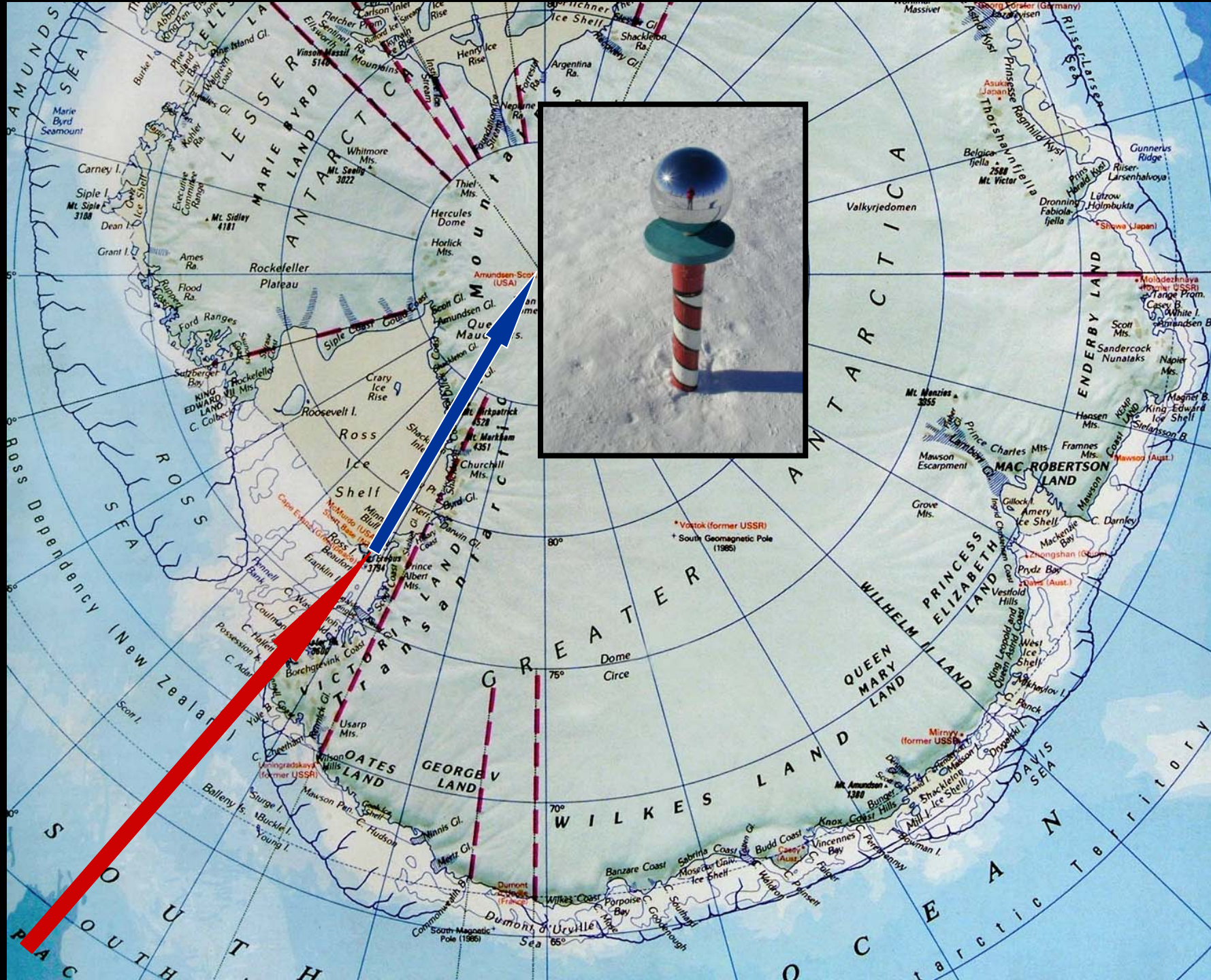




McMurdo Station, Antarctica













South Pole



AMANDA— 1 mile deep







GEOGRAPHIC SOUTH POLE



ROALD AMUNDSEN

DECEMBER 14, 1911

"So we arrived and
were able to plant our
flag at the geographical
South Pole."

ROBERT F. SCOTT

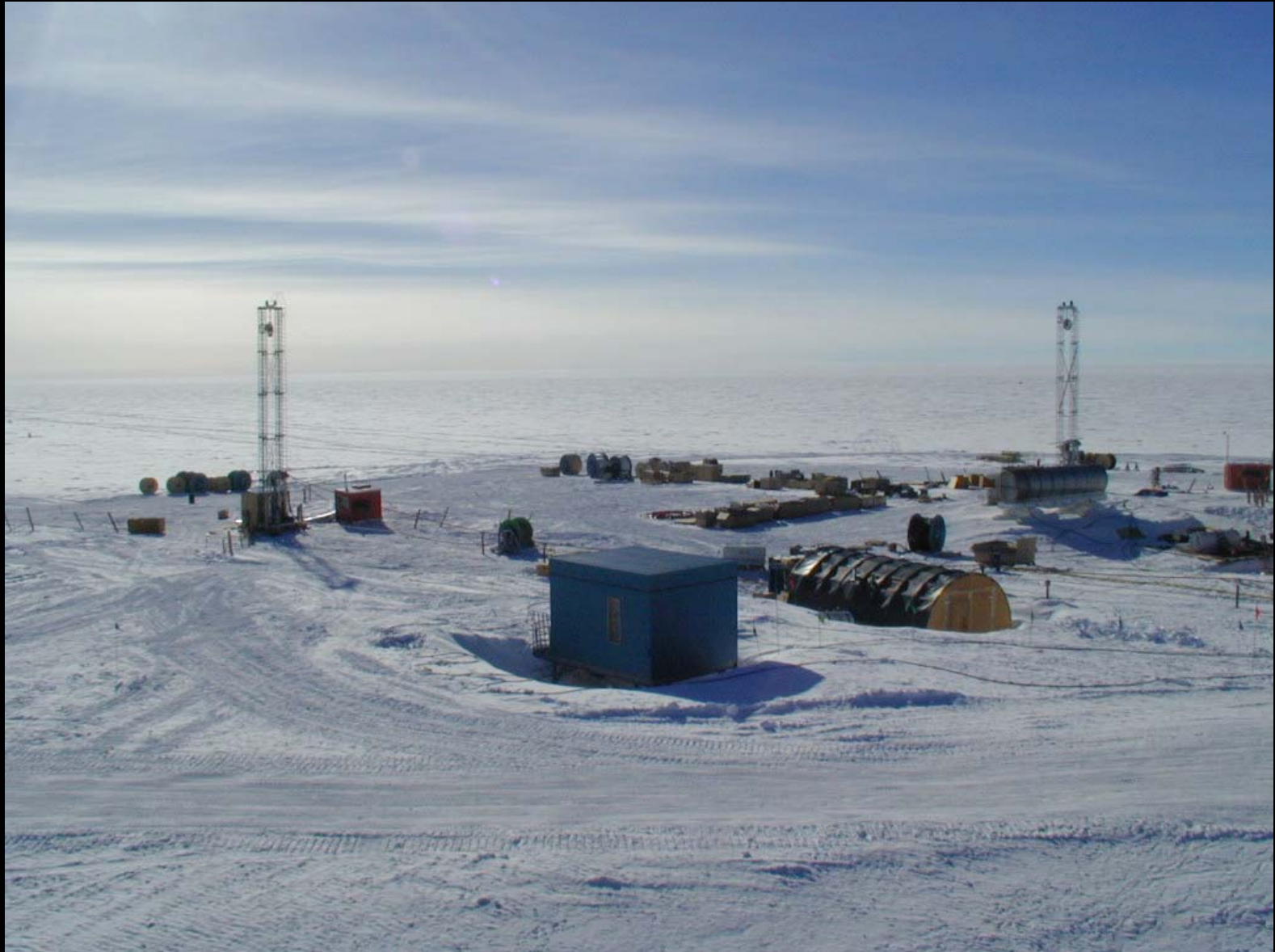
JANUARY 17, 1912

"The Pole. Yes, but
under very different
circumstances from
those expected."

ELEVATION 9,301 FT.



Drilling to 2 km Depth













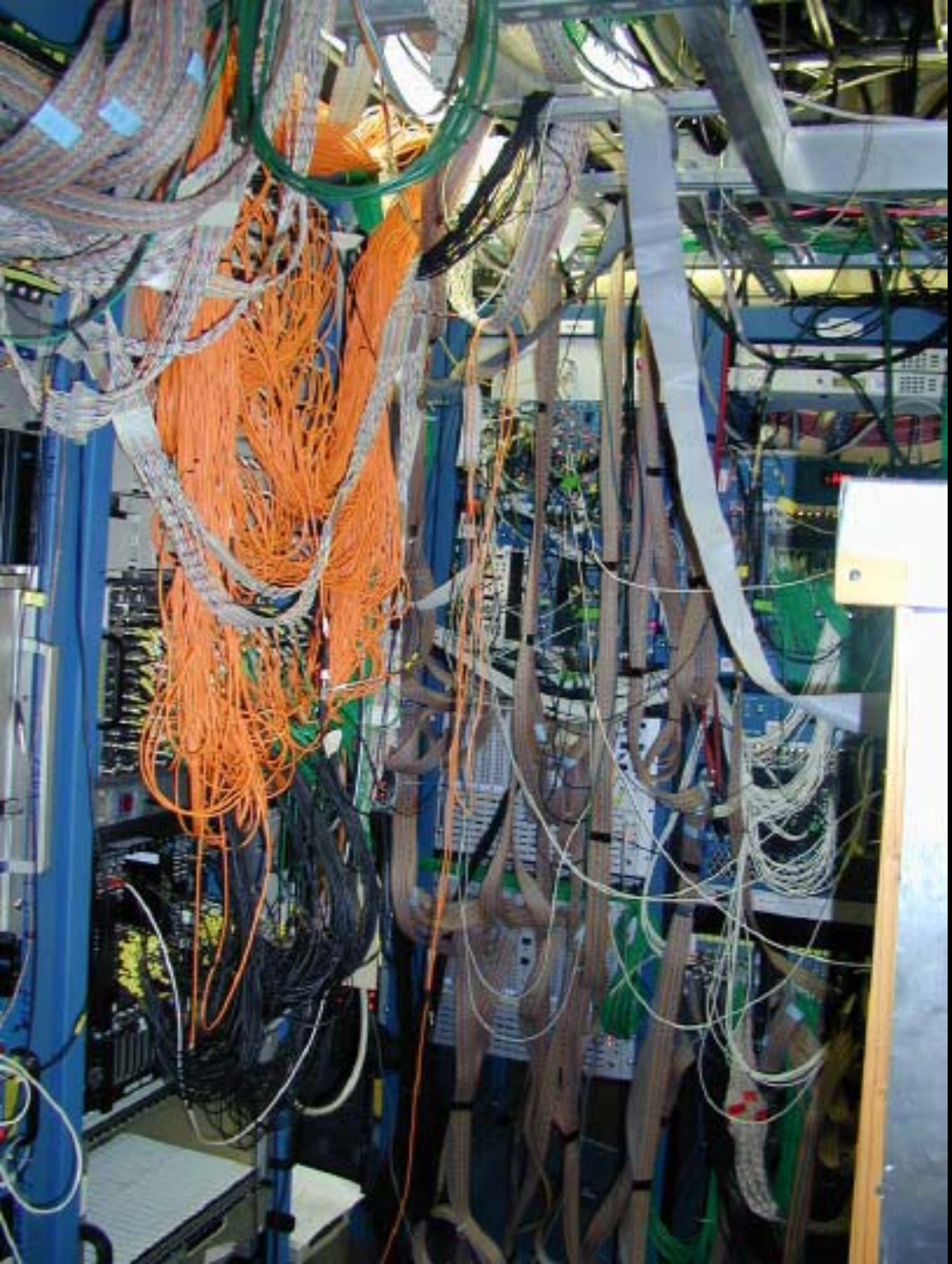














00:01 01.01.2000



Back to work



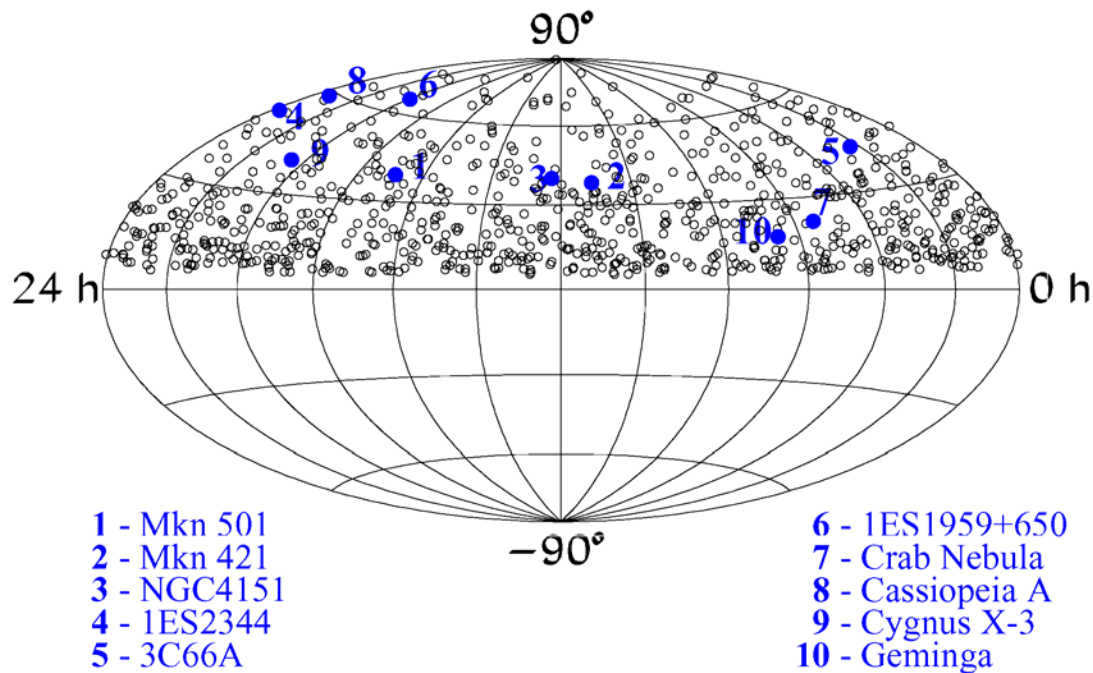


Fig. 8.— Sky plot of 815 events obtained from the point source analysis. Horizontal coordinates are right ascension and vertical coordinates are declination. Also shown are the sky coordinates for ten potential high-energy neutrino sources.

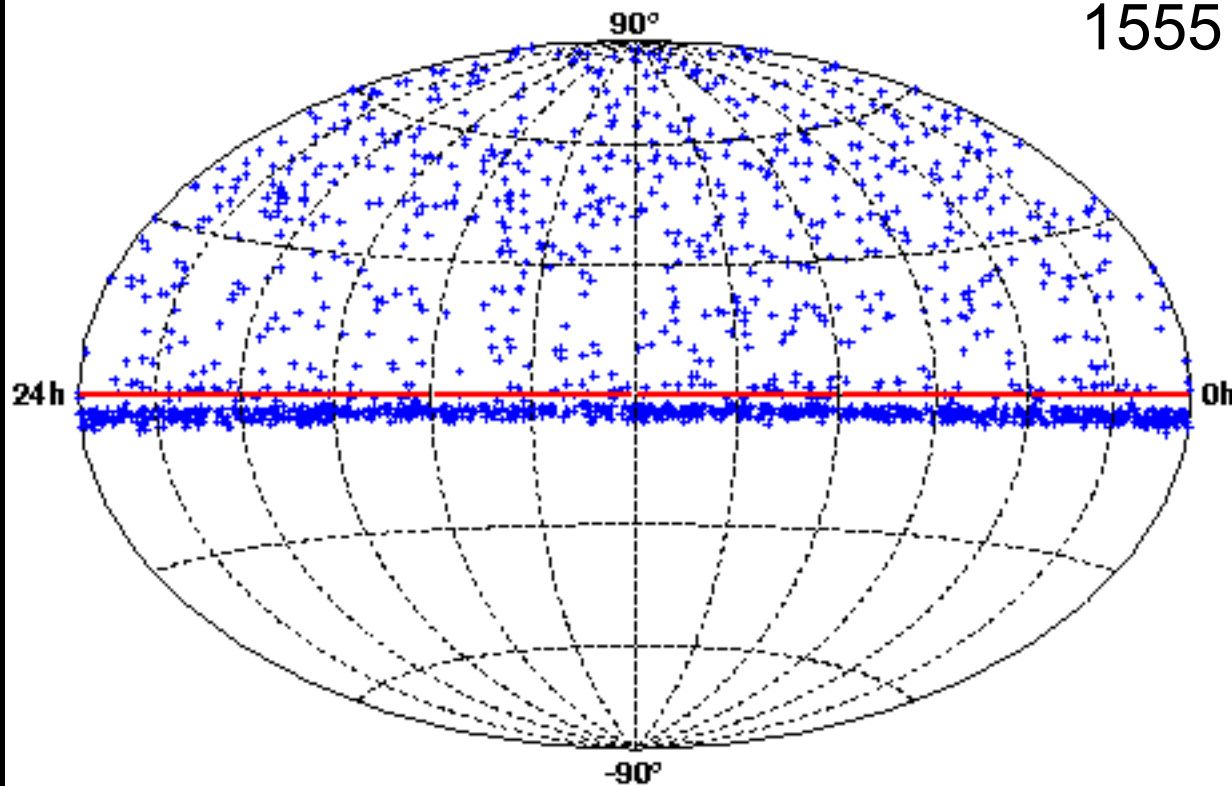
No evidence for point sources

Events consistent with atmospheric neutrinos

AMANDA II 2000

Additional observations consistent with atmospheric neutrinos

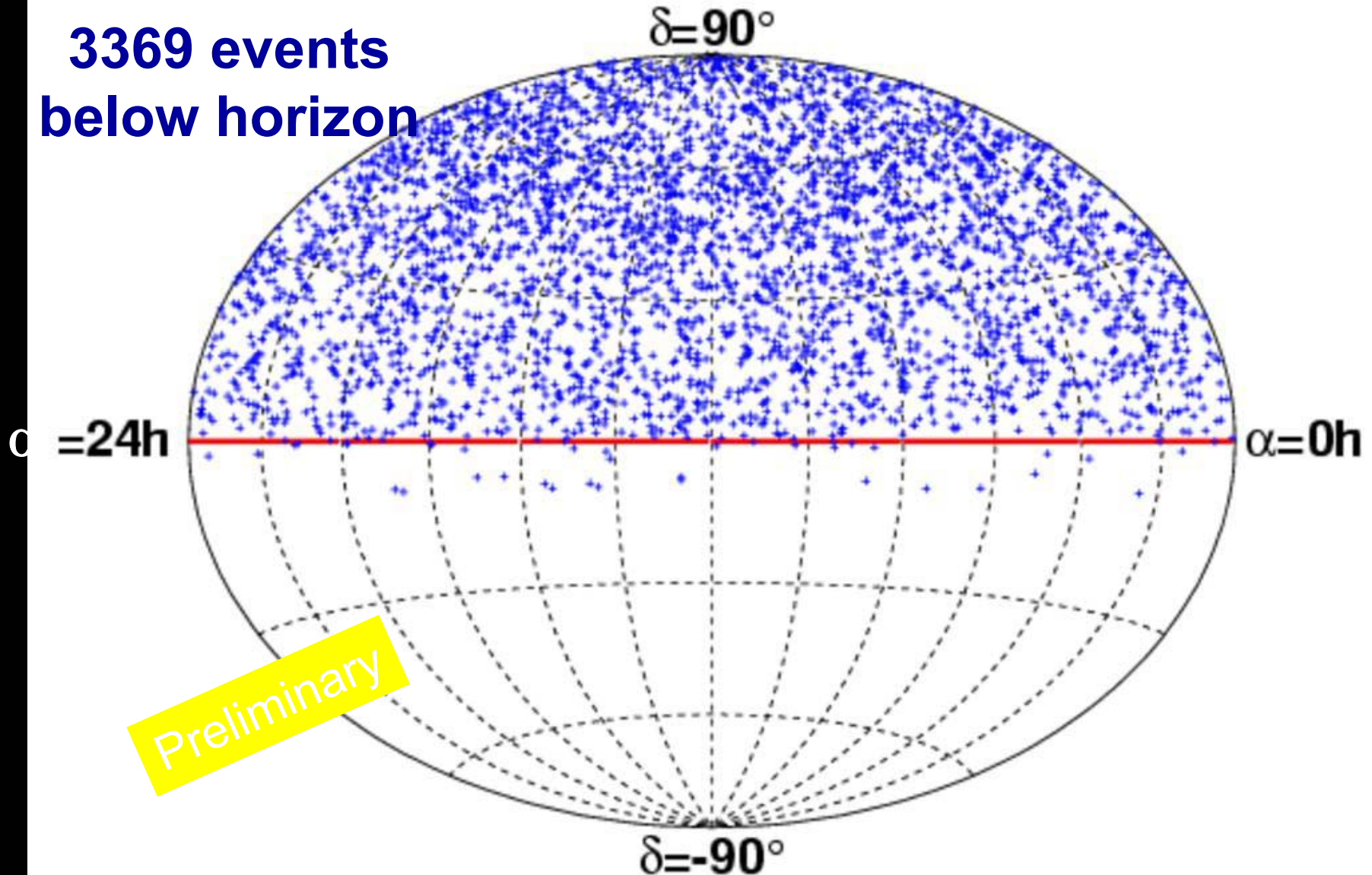
1555 Events



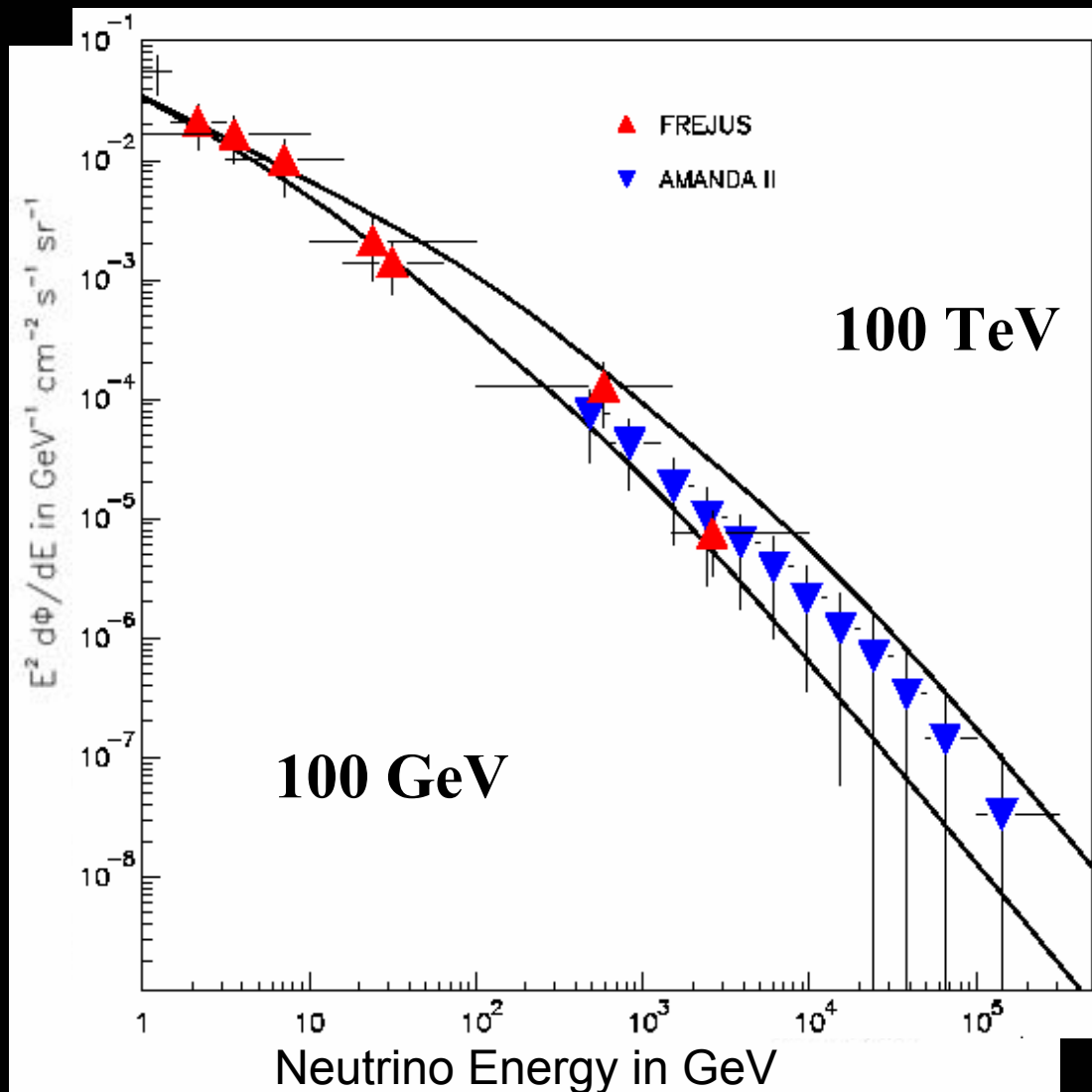
AMANDA skyplot 2000-2003

optimized for best sensitivity to E^{-3} – E^{-2} sources

3369 events
below horizon



Atmospheric ν 's as Test Beam



AMANDA Results

search for extraterrestrial ν :

- excess of diffuse flux at high E_ν
- search for point sources
no effect seen up to now:
limits at or close to most optimistic model expectations

searches for exotica

- WIMPS
- Monopoles
no effect seen up to now

Larger detector will improve sensitivity
and discovery potential.

P.M.



Evolution
Ihre geheimen
Pläne für die
Zukunft
unserer Erde



Mai 2003 Deutschland 3,00 €

Österreich 3,50 € • Schweiz 6,50 sfr • BeNeLux 3,60 € • Frankreich 4,10 €
Griechenland 4,75 € • Italien 4,10 € • Portugal (Cont.) 4,10 € • Slowenien SIT 9,90 • Spanien 4,10 €

Jagd auf Neutrinos:
Am Südpol startet
PROJEKT ICECUBE

Das größte Experiment der Welt

Sicherheit im Tunnel
Was die Experten aus
dem Gotthard-
Unglück gelernt haben

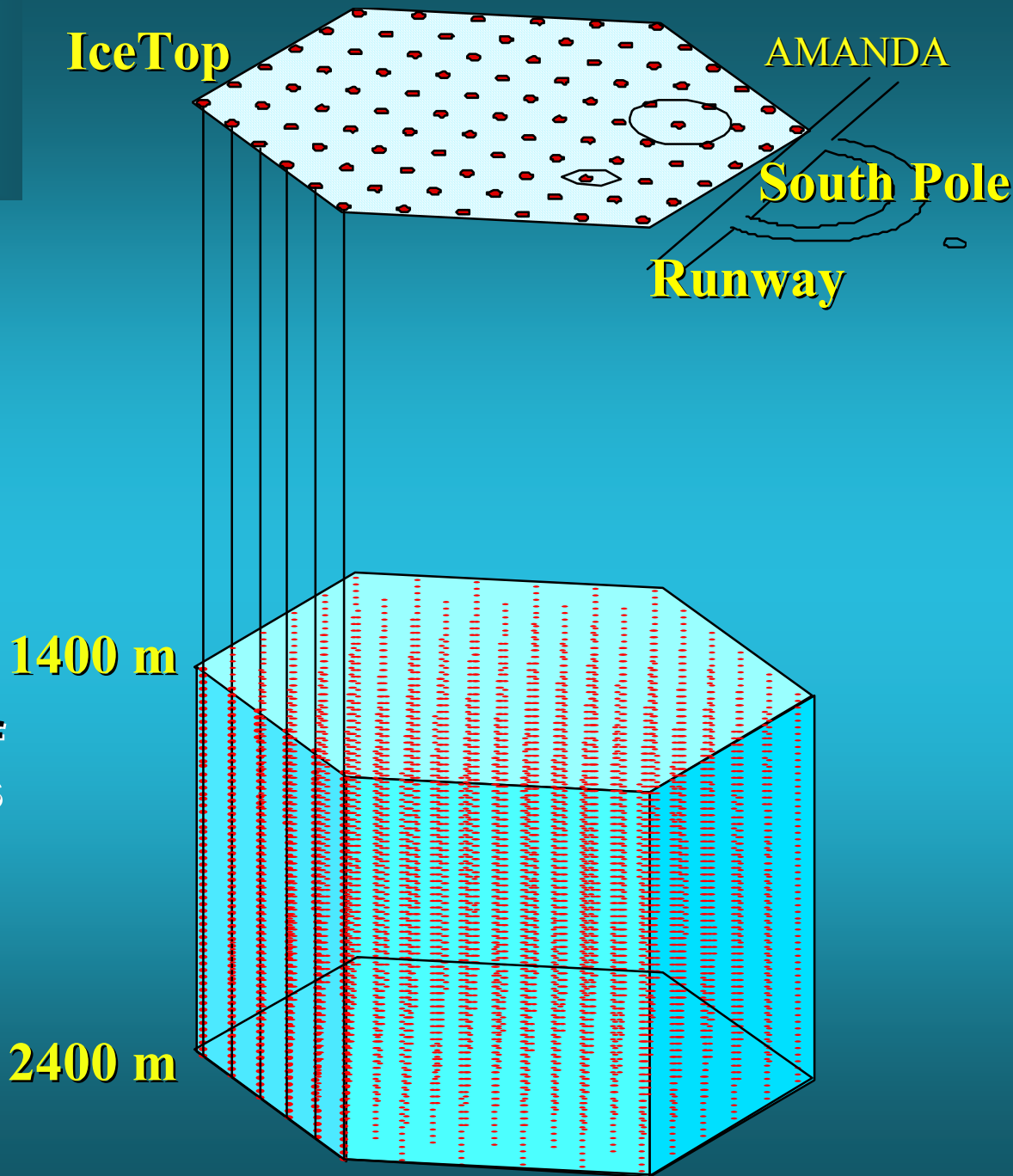
Höhenflüge
Mit kühnen Ideen will
Boeing den Konkurrenten
Airbus überflügeln

Die Krieg AG
Private Militär-Firmen
im Vormarsch. Gefahr
für die Demokratie?

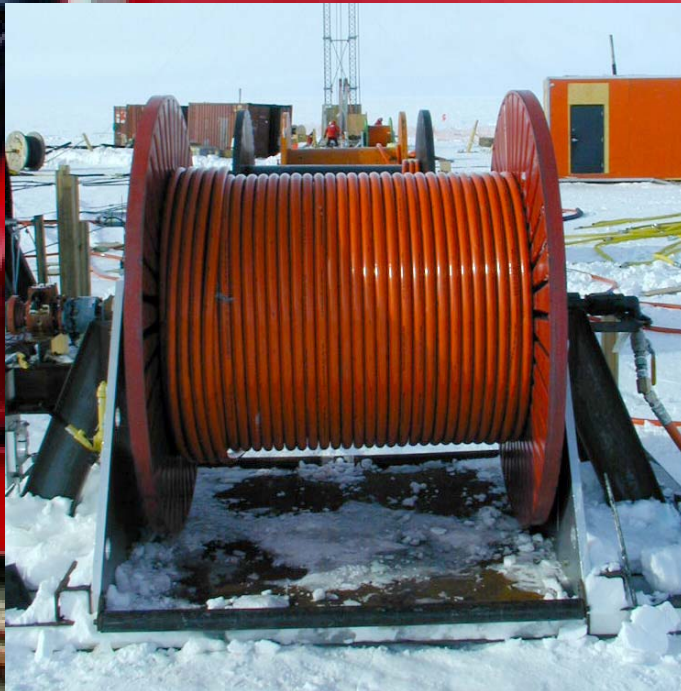
Astronomie
Faszinierend fremd: So
sieht der Himmel über
fernen Planeten aus

IceCube

- 80 Strings
- 4800 PMT
- Instrumented volume: 1 km³ (1 Gton)
- IceCube is designed to detect neutrinos of all flavors at energies from 10^7 eV (SN) to 10^{20} eV



The Hose Winch



3 km high-pressure hose

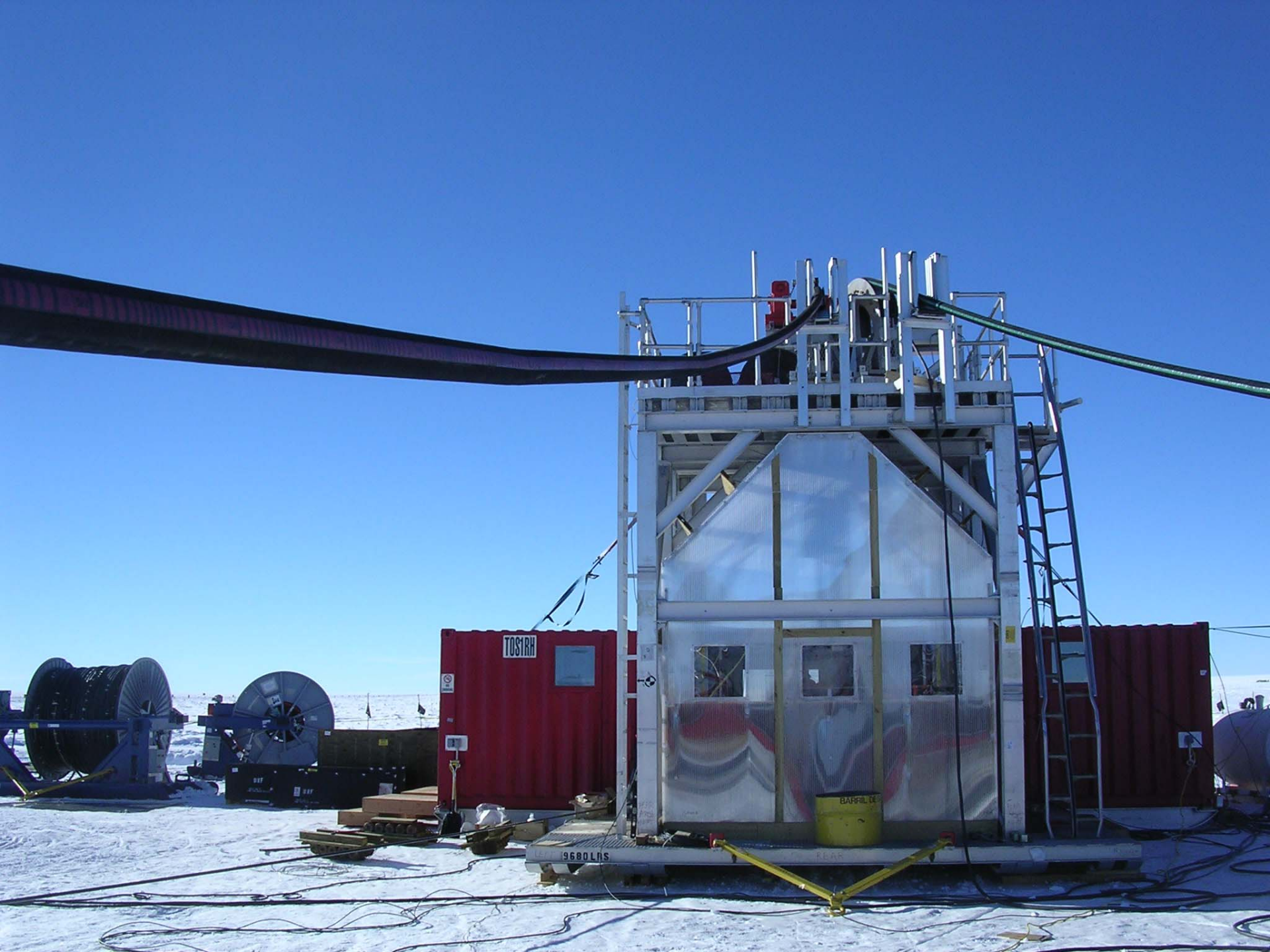




















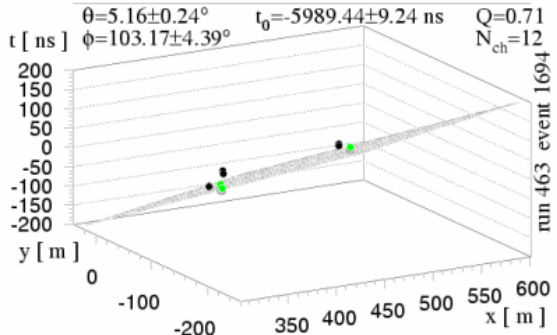
```
00:00 /proc/driver/domhub/card5 -- 00aw  
00:00 /proc/driver/domhub/card6 -- 00aw  
00:00 /proc/driver/domhub/card7 -- 00aw  
00:00 A DOM result: Card 0 Pair 0 DOM A is communicati  
00:00
```



```
DOM B is communicati  
me/testdaq/ domterm C
```

5.....

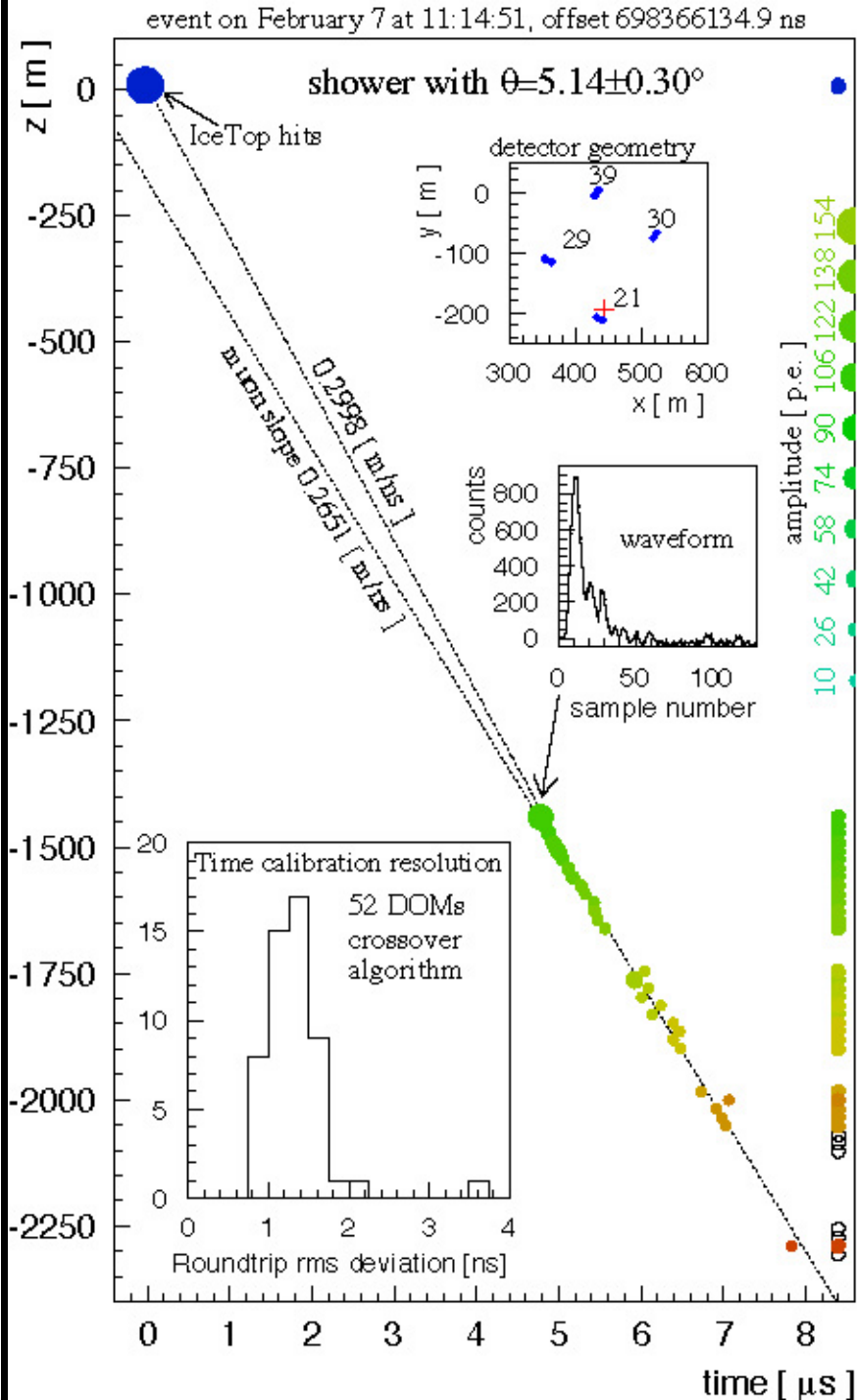
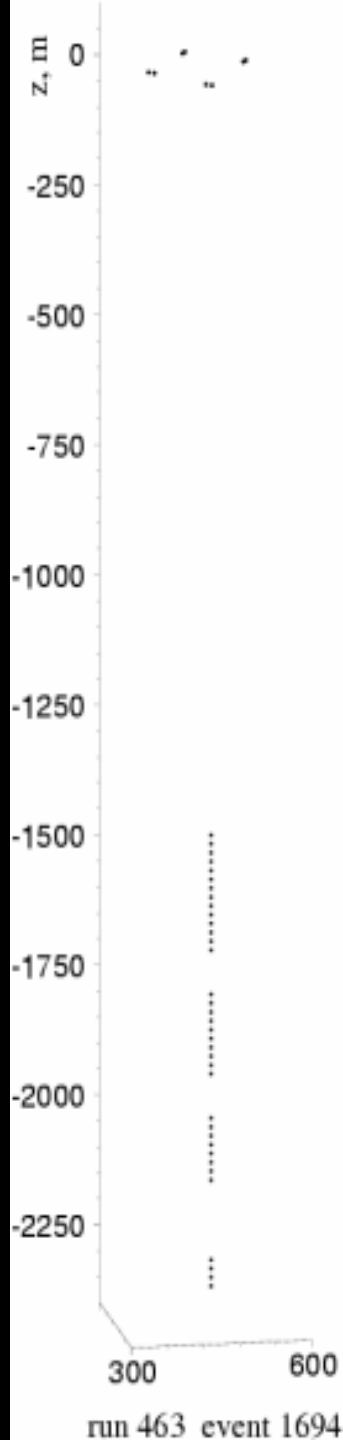


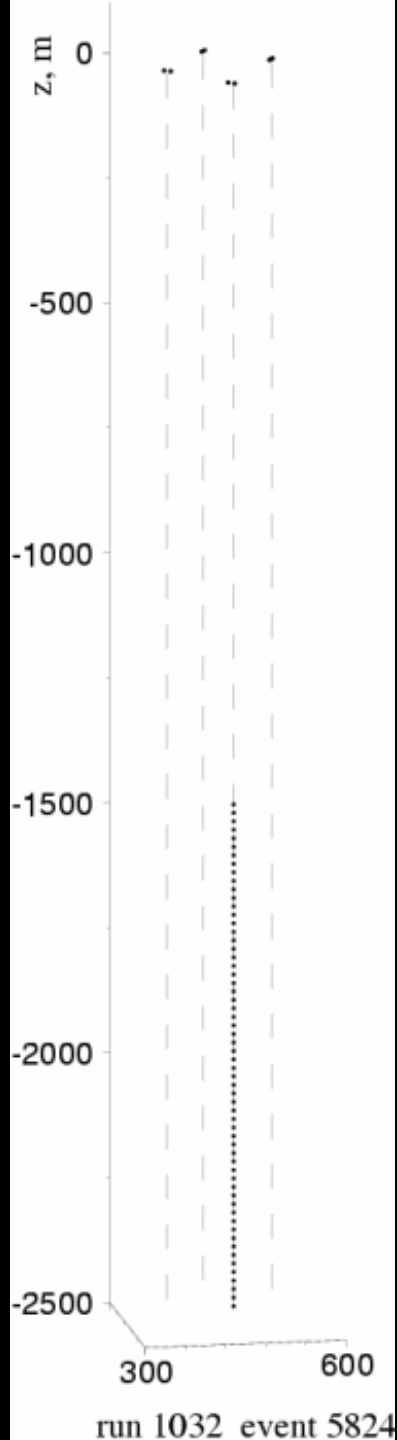
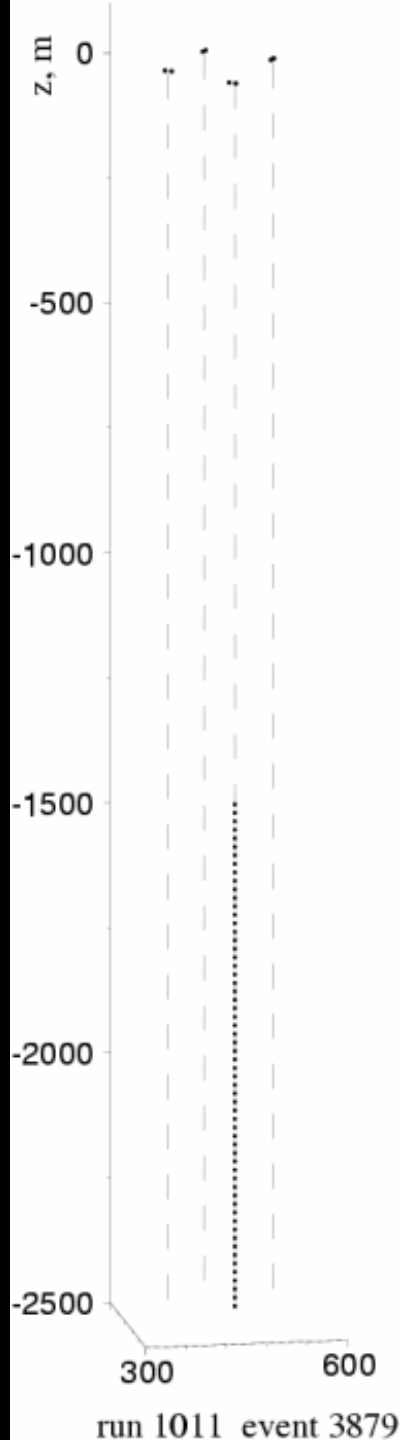


Surface Air Shower
array - IceTop

First in-ice
tests of the
(LBNL)
Digital
Technology
in IceCube

Feb 7, 2005



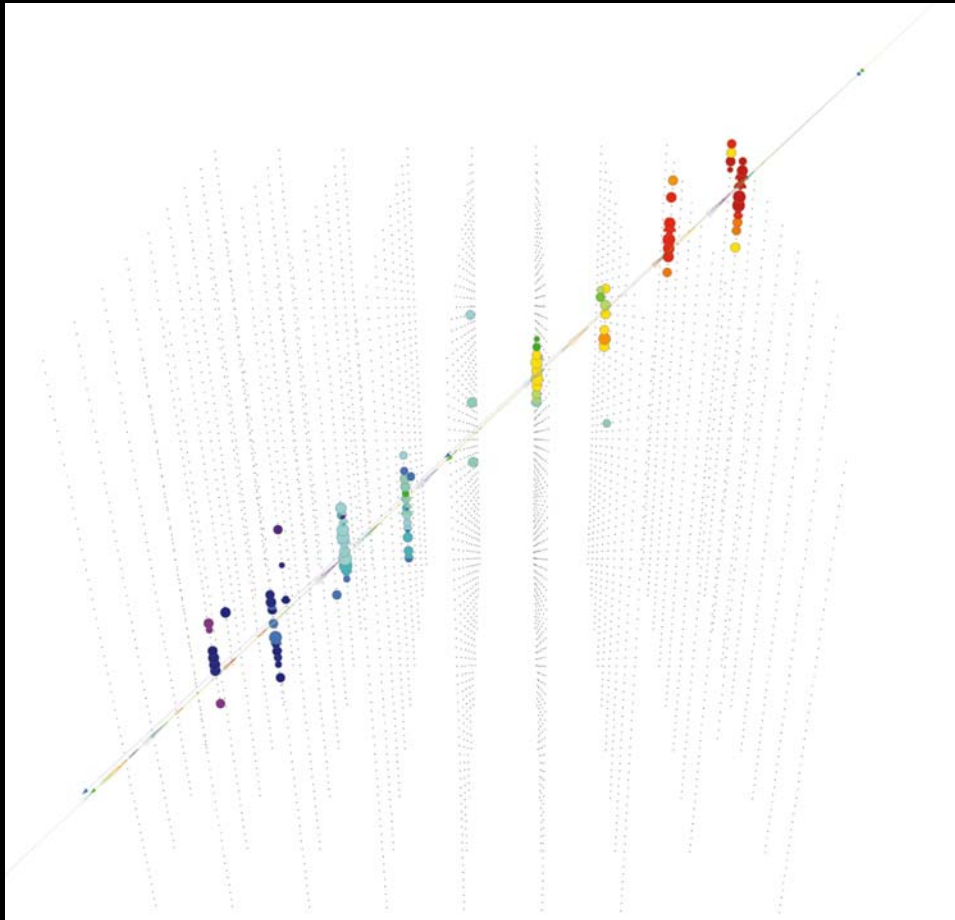


*All 60 Digital
Optical Modules
work and
perform
according to plan
(actually, better
than spec)*

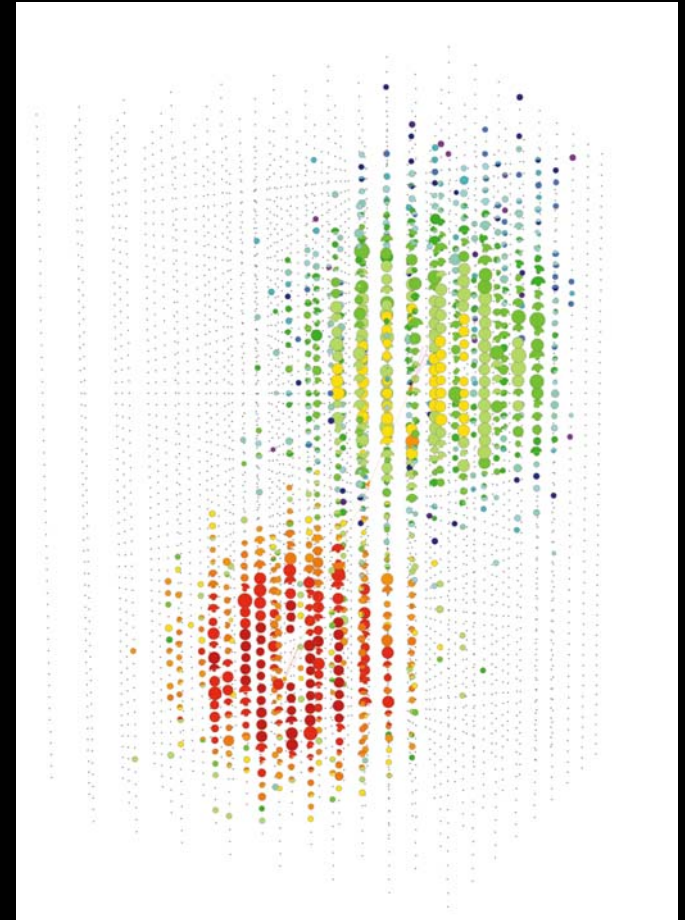
*Designed for
Long term
reliability - time
will tell*

Simulations of Events in Ice Cube

A 70 Tev Muon



A ν_τ "double-bang"



IceCube Time Line

- Dec 2003 Drill shipped to Antarctica
- Jan-Feb 2005 Deploy ~~4~~ strings 1
- Dec-Feb 2006 Deploy 10 strings
- Nov-Feb 2007 Deploy 16 strings
- Nov-Feb 2008 Deploy 18 strings
- Nov-Feb 2009 Deploy 18 strings
- Nov-Feb 2010 Deploy 14 strings

Cost ~ US \$270 Million

The LBNL IceCube Group

December 2004



IceCube Institutions

USA

Bartol Research Institute
Clark Atlanta
Lawrence Berkeley National Lab
Penn. State. U.
Princeton U.
South Pole Station
Southern Univ.
U. Maryland
U.C. Berkeley
U.C. Irvine
U. Kansas
U. Wisconsin

Japan

Chiba

Europe

Belgium

Bruxelles

Mons

Germany

DESY-Zeuthen

Mainz U.

Wuppertal U.

Sweden

Kalmar U.

Stockholm U.

Uppsala U.

Netherlands

Utrecht

U.K.

U.C. London

What do we hope to learn in the future?

- Neutrino Properties
 - Absolute mass scale
 - Nature of neutrinos: Majorana or Dirac?
 - Mixing matrix (determines oscillations)
- Neutrino Astronomy
 - Discovery of (cosmic) point sources
 - Map the neutrino sky
 - Discover exotica or rule out models

THE UNEXPECTED

